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Shock Loading of Ta: Yield and Hardening Behavior of Polycrystalline and Oriented Single Crystals

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DISCLAIMER

SHOCK LOADING OF TA: YIELD AND HARDENING BEHAVIOR OF POLYCRYSTALLINE AND ORIENTED SINGLE CRYSTAL SAMPLES

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ABSTRACT: We are undertaking a series of shock compression experiments on polycrystalline and oriented single crystal Ta to investigate the fundamental mechanisms controlling dislocation behavior in Ta and other bcc metals at high strain rate. We compare experimental results to those calculated using an explicit 1-D computer code using the Steinberg-Guinan-Lund rate dependent model (Steinberg and Lund [1989]) to describe the strength properties of Ta in these calculations.

INTRODUCTION: Accurate modeling of many phenomena related to dynamic deformation and failure requires a precise understanding of material behavior in the weak shock regime. The weak shock regime is defined as the range of intermediate pressures in which a material is shocked above its elastic limit, but below the pressure in which a single strong shock wave is developed in the material. The elastic "precursor" wave propagates at a higher velocity than the plastic deformational wave (which may or may not be steady). A recent study of the dynamic properties of Ta in the weak shock regime has noted a discrepancy in the relative timing of the elastic and plastic waves predicted by calculation and measured using VISAR (Furnish et al. [1996]). We have carried out a series of experiments and calculations to verify this discrepancy and evaluate the possible influence of crystallographic texture on elastic and plastic wave speeds in Ta.

PROCEDURES, RESULTS AND DISCUSSIONS: Disks of polycrystalline Ta (3 mm by 30 mm) or single crystal Ta (2-3 mm by 20 mm) were cut from known materials and polished to remove surface damage. Acoustical properties were measured using the Papadakus technique. Rolled Ta plate is known to exhibit significant textural anisotropy leading to non-uniform strain during mechanical testing (Schwartz, et al.[1998]). Acoustical tests detected slight shear wave echos caused by reflections within the sample, indicating possible crystallographic banding.

Single crystal samples were cut and oriented with either [100] or [-2 9 20] orientations parallel to the shock direction. These orientations were chosen to compare and contrast wave profile development in high and low symmetry configurations with respect to crystallographic slip planes and directions.

Samples were shock-loaded to pressures in the range of 4-11 GPa using Lexan and sapphire impactors. Shock wave profiles were measured using a VISAR system and wave speeds were independently timed using piezoelectric signal pins.

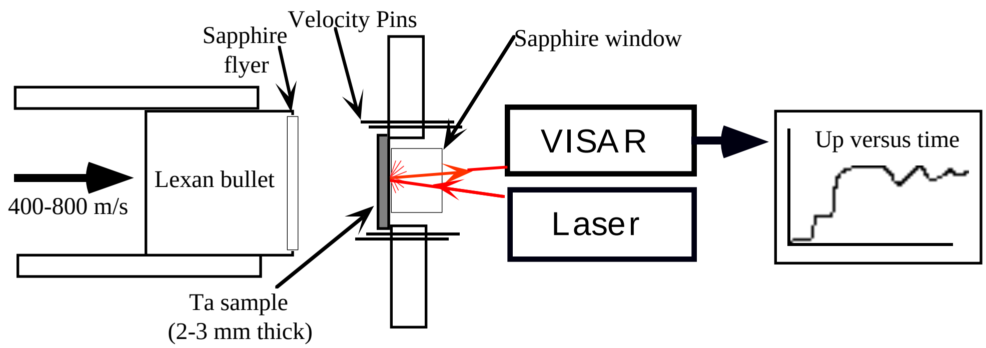

Figure 1: Diagram of experimental configuration

Experiments were carried out in both a spall configuration (free rear surface) and release configuration (with a window on the rear surface) (Fig. 1).

Previous studies of the dynamic properties of Ta have noted a discrepancy in the relative timing of the elastic and plastic waves predicted by calculation and measured using VISAR (Furnish et al. [1996])(Fig. 2).

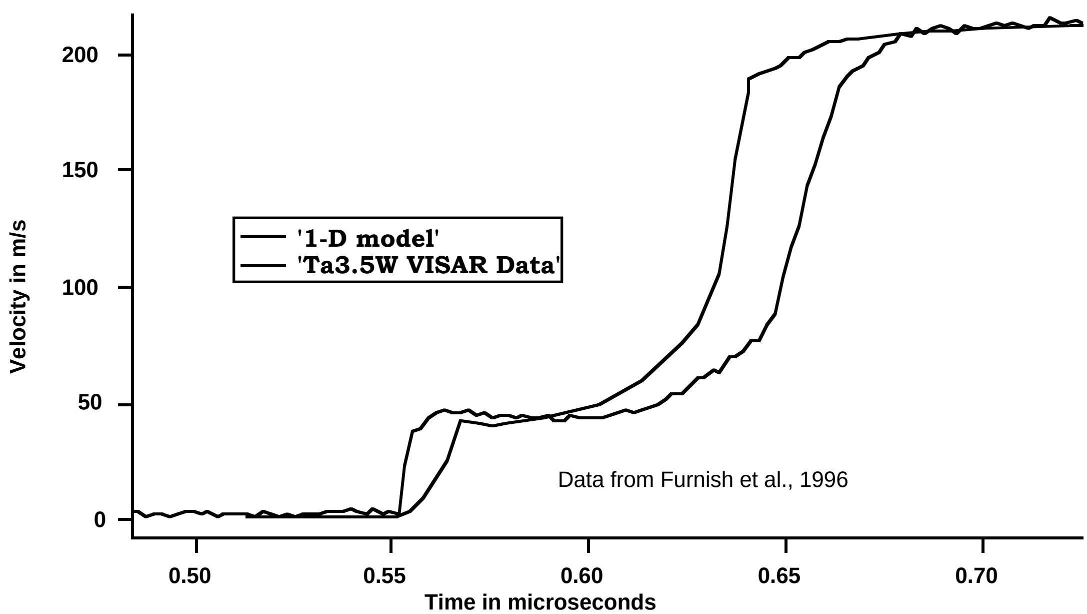

Figure 2: 1-D calculation and and VISAR measurement of plastic wave offset in Ta3.5%W alloy differ significantly (from Furnish et al. [1996]).

Our preliminary results on polycrystalline Ta confirm the reported discrepancy with the plastic wave arriving later, and rising more gradually, than that predicted by calculation (Fig. 3).

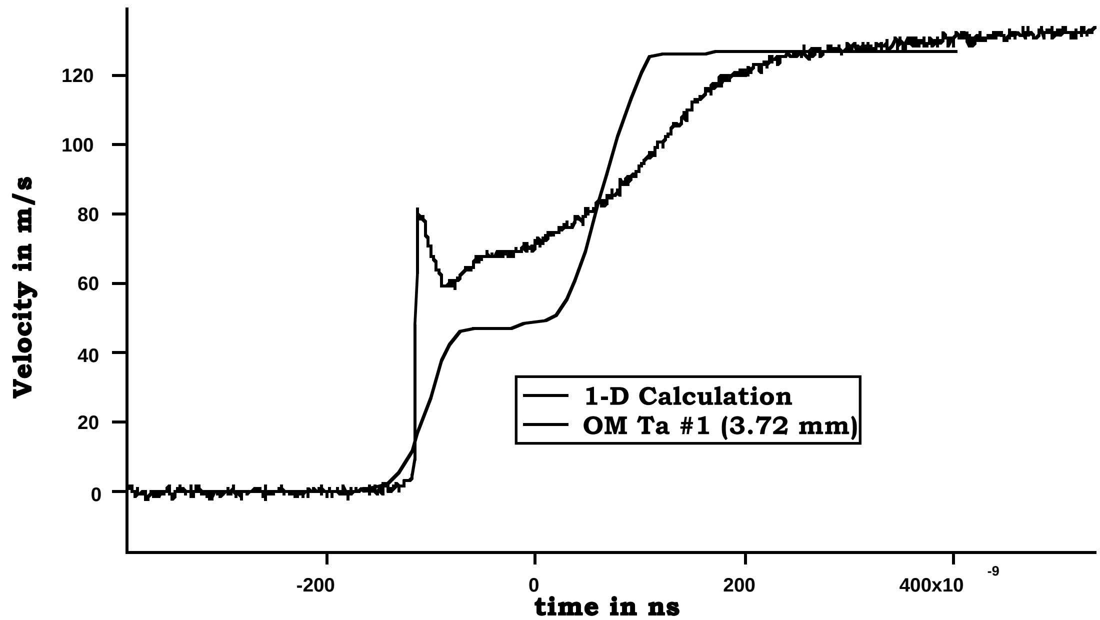

Figure 3. A comparison of shock wave profiles in Ta measured with VISAR and calculated using an explicit 1-D code.

Rather than an effect of crystallographic anisotropy, this discrepancy may arise from the assumption of a linear extrapolation Us-Up data gathered in the strong shock regime. In the weak (two-wave) shock regime the speed of the possibly unsteady plastic wave may deviate significantly from that predicted by a linear extrapolation of Us-Up data (Fig. 4).

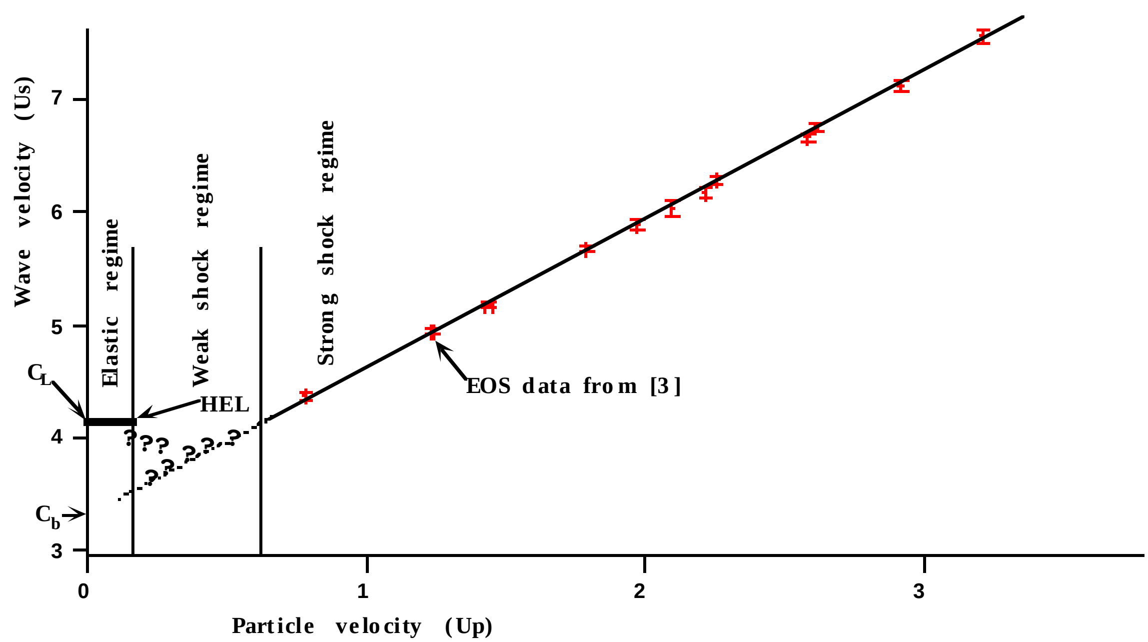

Figure 3. Us-Up behavior of Ta. EOS measurements are only made in the strong shock regime. In the weak shock regime plastic wave speeds may deviate significantly from a linear extrapolation of Us-Up data. EOS data from Mitchell and Nellis [1981].

CONCLUSIONS: The weak shock regime represents a challenging area for the modeling of the dynamic response of Ta. With our ongoing experiments on single crystal Ta and future work measuring wave profiles of Ta we hope to further evaluate and refine the Steinberg-Guinen-Lund strength model for use in a wide range of computer code simulations.

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